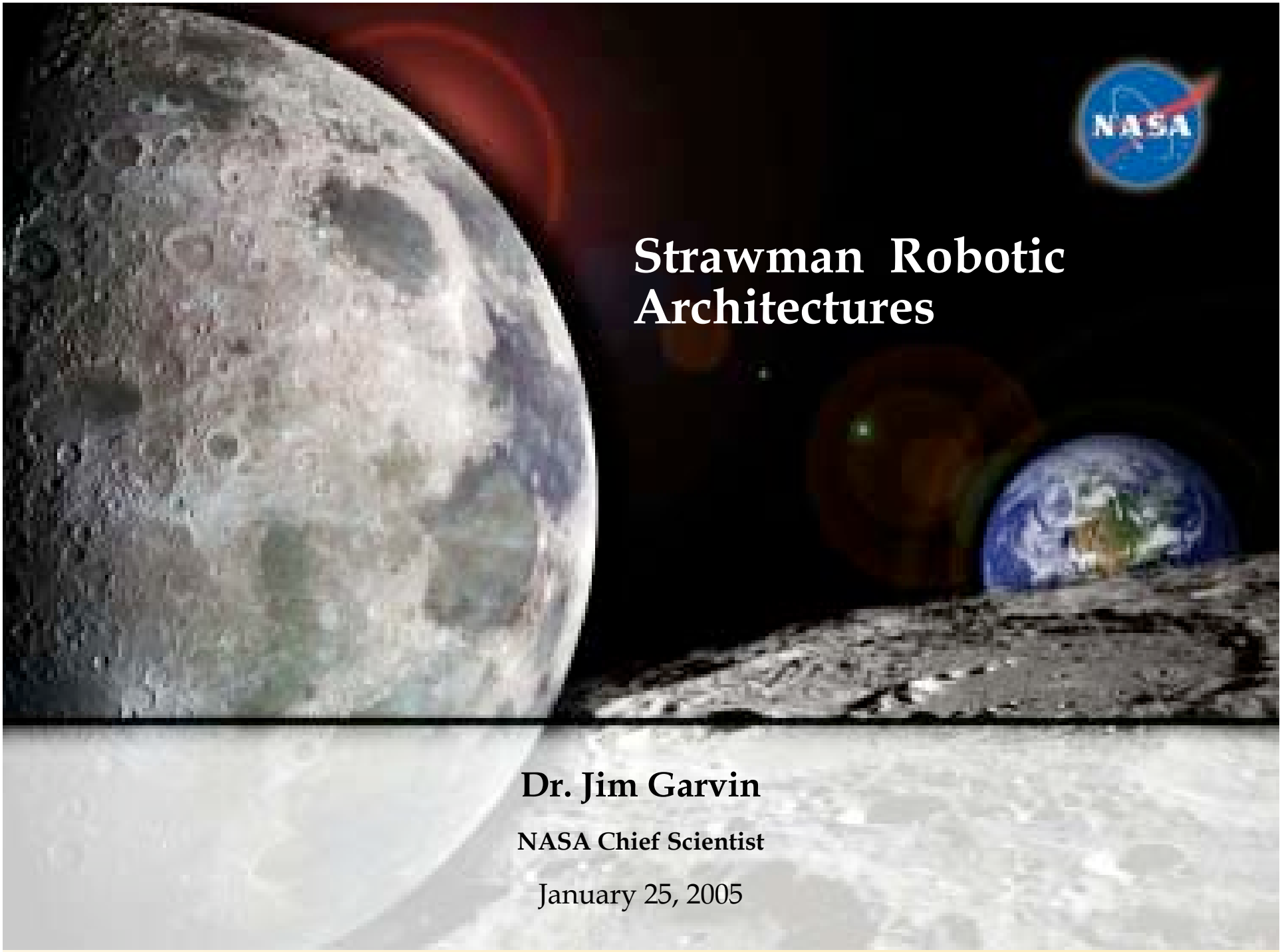


Strawman Robotic Architectures

Dr. Jim Garvin

NASA Chief Scientist

January 25, 2005

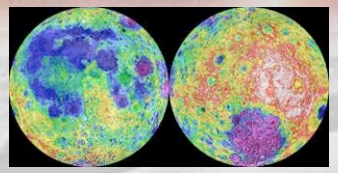
Lunar Architectures

A 1st Step
Back to Human
Exploration...

Approach:

* *use what we have!*
* *leverage int'l missions*
* *leverage NASA pgm's*
* *max value of LRO!*
* *be inclusive*
* *cost-constrained*
* *science enabling*
* *links to Mars "conops"*

Lunar Precursors:



Classical Science

Robotic Precursors, human missions

Hypothesis driven (SMD)

Flight Demos etc.

Integrated Mission Set

Applied Science Research

Measurement driven (ESMD,SMD)

Engineering Capability driven (ESMD,SOMD)

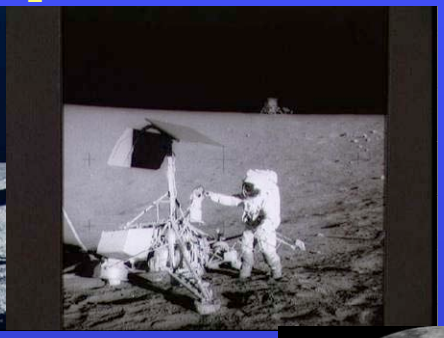
Engin./Tech. Demo's

Human on-site Activities

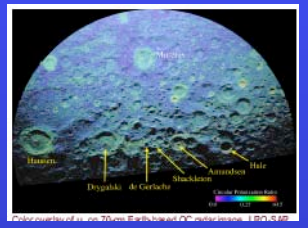
Lunar Precursors should support all 3 aspects of integrated Exploration!

Surveyor
1960's

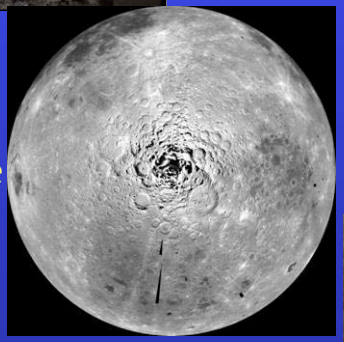
Apollo '69-'72



Earth-based Radar



Clementine
1994

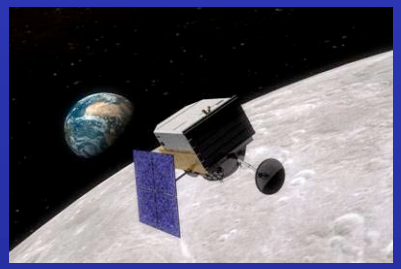


Lunar Prospector 1998

Selene (2007)

ESA SMART-1
(2005-...)

LRO 2008



Lunar Surface:
2009 - humans

Lunar pathway context

LRO: A First Step…

Example Questions and **Notional** Responses

2015 - 2020

Deliver & operate supporting infrastructure as needed in support of human exploration

Block II CEV – Human Flight

Must we return diverse biological Experiments to fully mitigate human issues?
Robotic Biosentinel Return?

Can local resources be utilized and how so?
Landed ISRU Demonstration
Lab/plant?

Can necessary infrastructure be forward based?

Communication & Navigation
Station and laboratory (ISRU?)

How can performance of CEV critical elements be rapidly & inexpensively demonstrated?

Constellation Candidate Technology Demonstration?

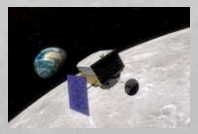
Block II CEV - CDR

What must be done to enable routine access to the Moon?

Block II CEV - PDR

Farside Gravity Mapper and Orbital Regolith mapping in 3D?

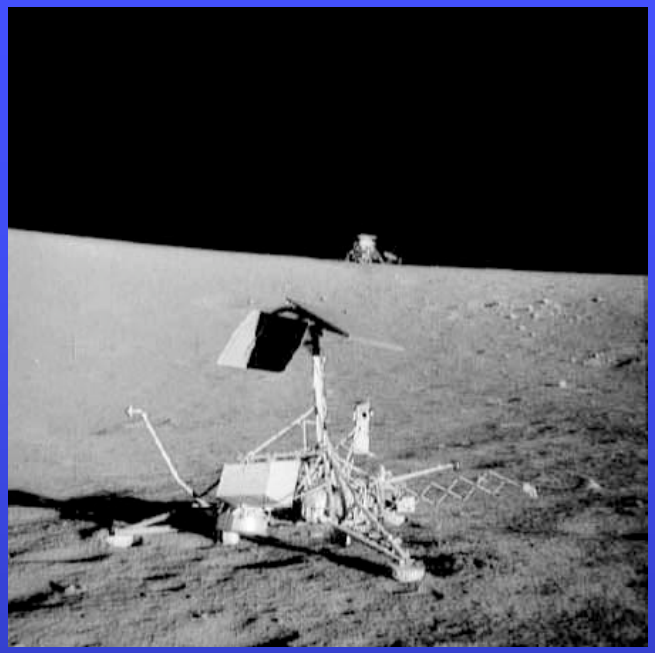
Can the radiation environmental effects be mitigated? Validation of ice as a resource. Biological effects?
Resources & Biological Effects Probe? Regolith/Biosentinel Experiments?



How bad is the radiation environment for humans? How can we land at the Poles? Are there potential resources (ice)?
Lunar Reconnaissance Orbiter

2008

What's Beyond LRO? *Some options*



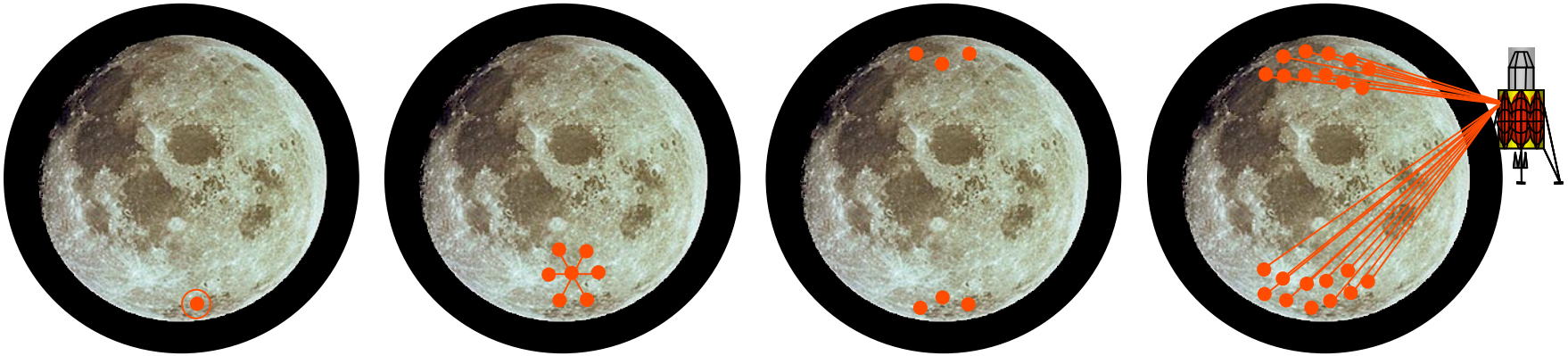
Beyond LRO?: Exploration of a potential resource: *Validation of water ice and in situ biological sentinel experiments?*

Beyond LRO?: *Follow-on to LRO, filling key gaps, including regolith characterization in 3D, far-side gravity, landing site hazards, Telecomm. infrastructure?*

Beyond LRO?: *potential lunar biol. expt. returns and demos?*

Examples of Surface Interrogation Techniques

(courtesy GSFC RLEP)



 Lunar Rover	Lunar Mortar	Lunar Probes	Lunar Samplers
Rovers require larger LV capability to provide detailed investigation of a localized area. Not well suited to dark crater operations at 50 deg K. Travel somewhat limited by sunlight. Needs drill for depth penetration, or EM sounding equipment; may need special robotic sample handling gear.	Mortar type probes deployed from central lander or descent craft can cover a larger area and perform short lived investigations of dark craters before freezing, using central craft as a data relay. Can use kinetic energy for depth penetration.	Probes deployed from an orbiting mother ship can cover the globe, live for short times in cold traps, and relay data to the mother ship.	Sampling probes gather very small samples from many sites and return them to an orbiting lab on the mother ship. Increases lab instrument mass. Labs and probes from different missions can interact. Increased failure robustness. Communicate directly from mother ship. Technically less mature.
Soft landed rover systems mature in most areas; GSFC *Investigating cryogenic capability upgrades and drilling system*	Hard landers/penetrators much less mature: GSFC *Investigating current military hardened devices which would need different payload accommodations and navigational enhancements.*	*GSFC Investigating propulsion systems available for decent and hard/medium landing systems as well as instrumentation solutions with help of RFI's from industry/academia.*	*GSFC Investigating super micro technologies propulsion system staging, rendezvous and docking. Highly innovative somewhat more risky ultra simple short lived low cost, very small mass solution. Unique custom design not mature at this time.*

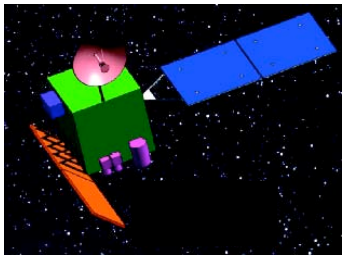
Priorities for human precursor investigations and technology?

- Search, define, and characterize polar deposits. *[LRO + tbd]*
- Navigational-communication *[LRO + tbd]*
- ISRU Oxygen, volatile extraction. *[beyond LRO...in situ]*
- Biological/radiation experiments *[LRO + in situ...]*
- Precision landing/hazard avoidance *[beyond LRO...]*
- Resource Mapping: orbital-mineral/chemistry, magnetics, gravity *[LRO + beyond, including in situ?]*

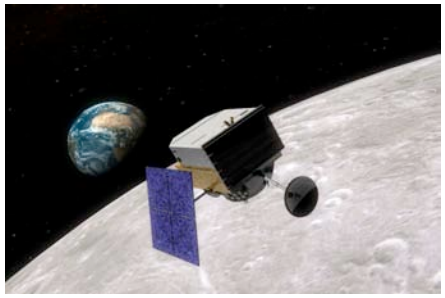
- Characterize regolith *Human-based ?*
  - Sampling,manipulation, in situ analysis, health & engineering problems (high-dust environment)
- Manufacturing of photovoltaic cells.
- Environmental impact & bio-organic contamination.
- High resolution topography of potential lunar base sites.[LRO]
- Validate shielding.
- Earth imaging

Notional Lunar Robotic "architecture"

Japan's *Selene*
(launch in ~2007):
Resources, color imaging,
farside gravity, ...

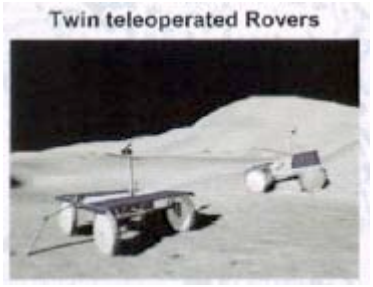


~2010
Lunar SAR
Regolith
Mapper w/
Biosentinel
Expt.?



LRO 2008:
Topo, ice, rad,
Cold traps,
Shadows, hazards

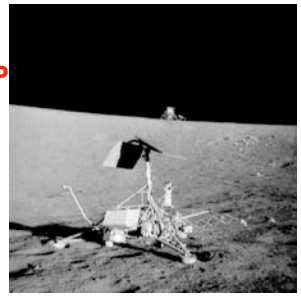
~2012-2014
Telerovers to S. Pole?



~ 2010 Exploration Tele-
Rovers for Resources etc.
(25km traverse "testbed")

2013-2015
LDEF Bio Diversity
Sample returns?

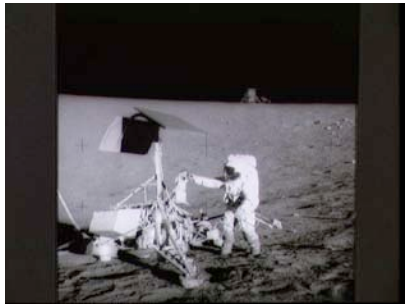
~2011-2012:
S. Polar sample return
(ice/rock/biosentinel ret.?)



~2009/10 RLEP
Lunar
Surface
Interrogator
(ice validator,
bio. to pole?)

2013-2015
RLEP
Landed ISRU
Demos, Lab?
Telecom.?

2016-2020 1st humans:
Testbed "visits"

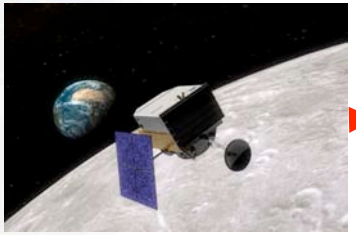


Lunar Exploration: *Example of one logic...*

Approached through Volatiles as a Resource

Is Water ice accessible on the Moon

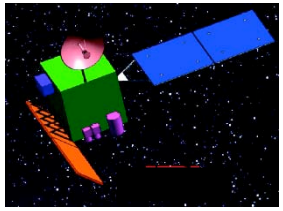
LRO 2008



Search for signs of water ice (T, H, z)

Is water ice detectable at high resolution (3D)

2010 SAR Orbiter



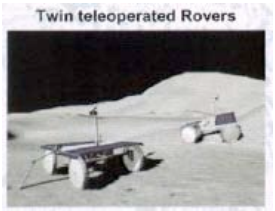
Search for radar reflectors (~ 10m resolution) down to 3-5 m depth for entire Moon

Water ice may not be preserved on Moon in any abundance over time

Is there abundant enough water ice to make ISRU cost-effective?

Is water (ice?) detectable at surface

2009/10 *"Lander"*



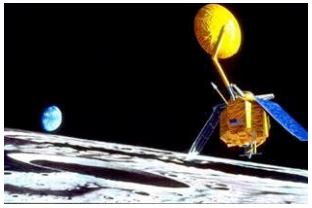
Examine materials on surface and perform ground-truth for ice detection

Are water-ice deposits elsewhere

Water ice may not be preserved on the Moon in any abundance over past 2-3 AE

Is water ice present, but not detected with these instruments?

2010 Lunar Orbiter



Search for water ice and related materials via other spectral/spatial regions

Is water ice abundant enough for ISRU, or to justify scientific analysis (sample return?)

Key

····· To be accomplished

Solid line is done/underway

Black is investigation start

Red if prior step yields negative result

Green if prior step yields positive result

Options: Depends on Human Missions

2010-2015 | 2015-2020 | 2020-2025 | 2025-2030

Robotic Missions → *Spiral 2* **Sortie Missions** → **Transition to Mars Exploration or Moon...**

Transition Options: ???

How we employ Humans on the Moon drives Pre-human robotic architecture

First Opportunity for Humans back to Moon (all models)

LRO

Objectives

- •Water ice (Amount?)
- •ISRU (how much?)
- •Infrastructure (T/C?)
- •Subsurface access?
- •Surface power demos (fission)?
- •In situ laboratories?
- •Biological responses (g, rad.) quantified?

Robotic-Human-Transition

- •Robotic pre-emplacement?
- •Robotic safety net?
- •Robotic "leave-behinds"?
- •Robotic mobility for humans?

- Demonstrate operational readiness beyond LEO capabilities
- Lunar Science : OPTIONS
- Extensive system test and crew experience performed on Earth or Moon (model dependent)

Description

PATHWAYS:

- •LRO + ~ 3 robotic missions
- •LRO + 1 landed mission
- •LRO + many (>3) till humans
- •LRO + commercial robotics
- •LRO + joint Int'l missions

Key Parameters

- # human missions
- Human surface duration
- Location or site dependencies?
- Infrastructure choices
- Role of Science on the Moon?

- Transition from Lunar to Mars only human missions???

Human Mission Models…*Robotic Antecedents?*

- **Evolution emphasis**
  - Multiple Sorties… crews do more, demos, resources, ISRU Expts.
  - Early human emphasis, ***limited robotic precursors beyond LRO***
  - Apollo Class sample return
- **Early Outpost**
  - ***Robotic emphasis for demos, resources, ISRU, sampling***
  - Commit to single centralized location..
  - Evolvable to hub/spoke model
- **Expedited *Moon to Mars*: "Gemini of APOLLO" Model**
  - Sortie missions to Moon of Apollo class (no ISRU) early
  - Terrestrial analogue emphasis prior to human sorties
  - ***May minimize robotic precursors after LRO and 1st landed mission?***
  - Earliest Mars visit possible
- **Commercial-emphasis (COMSAT model)**
  - Let Commercial Authority do NavCom, Data-buys, Habs, etc.
  - Commercial systems do Tele-operation for Business
  - NASA with commercial authority indemnify for 20 years etc.
  - NASA goes to Mars, abandon MOON
  - ***NASA robotic precursors beyond LRO and 1st Lander ideally limited***

4 Human Options from Cooke et al.